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INSTITUTE FOR DEFENSE ANALYSES

Report of UXO Technology Subgroup: Overview and Technology Assessment

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PREFACE

This document was prepared for the Director, Joint UXO Coordination Office (JUXOCO), in response to a task titled “Technical and Analytical Support to the Joint Unexploded Ordnance Coordination Office (JUXOCO) on Landmine and UXO Related Technologies and Issues.”

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EXECUTIVE SUMMARY

The Joint Unexploded Ordnance Coordination Office (JUXOCO) sponsored two workshops that discussed the present technology used by industry for environmental remediation, the use of newer technologies developed by the Department of Defense (DoD) for unexploded ordnance (UXO) remediation, the problems inherent in transitioning new technologies into UXO remediation tasks, and suggestions for cooperative efforts in the future. The Institute for Defense Analyses has reviewed open literature sources to independently assess the state-of-the-art technologies available for UXO remediation and compared both existent and emerging technologies against current and future industrial needs.

The DoD sponsors a wide spectrum of technology investments to support countermine, explosive ordnance disposal, humanitarian demining, range clearance, and UXO remediation. DoD technology investments in UXO remediation are carefully reviewed to ensure that the investments either build upon advancements achieved in other related DoD mission areas or represent technology investments unique to environmental remediation. A diverse palette of capabilities are evolving to support wide area assessment, production ground surveys, cued identification, standards and protocols, recovery and destruction, and decision tools. It is anticipated that this disciplined approach will achieve a progression of technology products that will build a solid technology base for UXO environmental remediation.

Industry surveys indicate that much of the technology investment has not transitioned to use in industry. Further, it is likely that much of the present DoD UXO environmental remediation technology investment may never find its way into common usage. Industry leaders point to several reasons the present UXO environmental remediation technology investment may not have the desired impacts on the future of their industry:

- Lack of user involvement in selecting and evaluating technology investments leads to products that may not meet the requirements of industrial use or may be useful in limited applications.
- At what point in development is a product deemed ready for transition?
- What process is used to determine that transition has been effected?

- Who (government, industry, or both) decides that an item has transitioned?
- Once transitioned, how are new technology products supported in the future?
- Can UXO remediation contracts be structured or bundled to encourage use of new technology products?
- How can industry recover their capitalization costs?

Government and industry need to work together to shape a meaningful transfer of useful technology tools to the UXO environmental remediation industry. Countermine and explosive ordnance disposal have built-in government programs to support the acquisition and fielding of new equipment through their project managers and laboratories. It is crucial that a transition path be identified for new technology into UXO environmental programs and that this path include the following basic properties: user definition, user evaluation, independent test and evaluation, spiral development, logistics support, and training.

Industry has proposed solutions that include government-furnished equipment and training, performance-based contracting, shared work using contract bundling, multiyear funded programs, and a program-based acquisition process. It is important that government and industry find common grounds to develop a meaningful technology transition process. Technology investments without user selection and evaluation result in hollow products. Lacking a meaningful transition path, even good products fail for lack of proper training, product improvement, and logistical support.

I. INTRODUCTION

The National Defense Authorization Act, Section 313 of PL106-65, states that the Secretary of Defense shall include in the report submitted to Congress in 2003 under Section 2706(a) of Title 10, United States Code, a comprehensive assessment of unexploded ordnance (UXO), discarded military munitions, and munitions constituents located at current and former facilities of the Department of Defense (DoD). This provision requires a report that gives a complete estimate of the current and projected costs, including funding shortfalls, for UXO response at active facilities, installations subject to base realignment and closure, and formerly used defense sites. The report must identify a plan for UXO response technology and provide detailed information regarding the obligation and expenditure of funds for UXO response research, development, test, and evaluation efforts. The 2003 report must also discuss the progress of the DoD's ongoing assessment and implementation of the Task Force recommendations as well as evaluate the applicability of Section 349 of the National Defense Authorization Act for Fiscal Year 1998 (Public Law 105-85).

II. PURPOSE OF REPORT

The purpose of this report is to provide an overview and technology assessment of environmental remediation of UXO. The material presented in this report is intended to present an accurate picture of the present (baseline) and evolving (research and development) technologies used to address the remediation of UXO. The report will address the investments being made by both government and industry in UXO remediation technologies and identify technology gaps and barriers to technology application by industry. The material contained in this report should serve as a resource to be used in the preparation of the report that the Secretary of Defense will submit to the Congress.

III. SCOPE OF REPORT

Since the invention of propellants and explosives, man-made objects such as rockets and cannonballs that use sensitive materials have failed to be initiated on command or have been left to deteriorate. Armed Civil War relics are occasionally found in the United States, and armed munitions from World War I are regularly dealt with in France and Russia. Methods for finding, locating, detecting, neutralizing, or removing UXO have evolved over time. Generally speaking, remediation is usually accomplished using the safest and least expensive approaches available. As an example, for reasons of cost, ground-penetrating radar and nuclear mine-detection techniques, which emerged during World War II, were not translated into high-technology approaches for environmental remediation. It is important to note that many new high-technology solutions available today may never be useful in environmental remediation for any number of reasons: technical complexity, training of skilled technicians, cost, applicability in different environments, robustness of technology to deal with many different sizes and types of ordnance, and the ability to perform in various soils and at great depths under the soil. Similarly, the costs in time and personnel to remediate UXO-infested areas are not determined solely or largely by the ability to detect UXO or discriminate UXO from clutter. Many elements are required to successfully remediate areas, and the problem differs substantially from one site or environment to another. Success requires careful, deliberate attention to all phases of the remediation process: archival search, site investigation, detection, access/excavation, neutralization, recovery, disposal, and monitoring and stewardship. The baselines and applicable technologies that address all phases of the remediation process will be assessed in this report.

In April 1998, the Defense Science Board Task Force completed its report, *Unexploded Ordnance (UXO) Clearance, Active Range Clearance, and Explosive Ordnance Disposal Programs*, which documented its two-phase study of UXO-related issues within the DoD. Since that time, there has been increased congressional interest in UXO programs in the Department, largely due to public interest in the reuse of former lands used by the military and population encroachment near ongoing operations on DoD ranges.

A. WHAT THIS REPORT INCLUDES

This report presents a rational response to the congressional requirement to assess the technologies currently available for the remediation of UXO. This report establishes a baseline of technology as it is currently employed. Further, this report discusses new and emerging technologies and their potential impact on the remediation process.

B. WHAT THIS REPORT DOES NOT INCLUDE

This report does not include a discussion of the DoD estimated costs associated with responses to remove UXO from closed, transferred, and transferring ranges.

This report also does not discuss DoD’s UXO response-technology investments, information regarding the obligation and expenditure of funds for UXO response technology research, development, test, and evaluation efforts, or the applicability of Section 349 of the National Defense Authorization Act for Fiscal Year 1998 (Public Law 105-85).

IV. TECHNOLOGY BASELINE

A. TECHNOLOGIES CURRENTLY EMPLOYED BY THE MUNITIONS RESPONSE INDUSTRY

1. Archive Search

The archive search sets the stage, and can set the standards, for the entire munitions response process. Search results are provided in an archival search report (ASR). The search begins with the establishment of data quality objectives and thereafter encompasses data collection, cataloging, storage, retrieval, analysis, and presentation. Currently, these activities are mostly done using manual processes. In part, this is necessary because the source material can be diverse in form, style, and content and not particularly adaptable to automated examination. Nonetheless, there is a clear appreciation in the UXO remediation community that automated data and information-management techniques and technologies offer benefits in various portions of the search process. There are no identified technology barriers to improved archival search reporting.

A prerequisite for best utilization of existing techniques and technologies is the establishment throughout the UXO remediation community of uniform, but adaptable, processes, procedures, and protocols for the entire remediation process. Some activity with this objective is underway.

The ASR is the basis for the next stage of the remediation process, the engineering evaluation/cost analysis.

a. Data Quality Objectives

Data quality objectives are established for each project. Benefits would accrue from a readily available database of reference, and perhaps standardized data quality objectives.

b. Data Collection

Currently, data collection is done from various sources, including paper files, paper maps, interpretations of aerial photos and maps, word processors, geographic information systems, computer-aided design tools, and site visits. The work is predominantly manual. Recognized needs are for agreed standardized map, data, and expository formats for the generators and collectors of reference information and data.

c. Data Cataloging

Currently, data cataloging is done manually for the most part, using the sources mentioned above. There are no standards for data cataloging (i.e., formats) among the UXO remediation community. The establishment of information and data standards, and the adoption of standard, open architecture data and information processing and distribution software would be of great benefit.

d. Data Storage

Currently, data storage is primarily in word processor files, scanner files, and similar storage. Standardized formats and software are not in place across the UXO remediation community. As stated in the preceding, establishment of information and data standards, and the adoption of standard, open architecture data and information processing and distribution software would be of great benefit.

e. Data Retrieval

The current practice is to use word processor files. The use of data and information standards in conjunction with efficient storage and retrieval utilities would provide great benefit.

f. Data Presentation and Visualization

Word processors, geographic information systems, AutoCAD software, paper maps, and photographs are all used. No doubt, they all will continue to be valuable. They could be integrated into, or be supplements to, standardized, but adaptable, formats in a system of data and information management.

2. Site Investigation

Site investigation encompasses a range of technology and operational processes. This activity is used to make site response decisions and to set site priorities. Site

investigation includes conducting site surveys; establishing sampling methodologies; conducting an initial inspection; determining appropriate diagnostic techniques; and developing data collection, cataloging, and storage systems. A mixture of low-technology and high-technology methods that reflect the dimensions of the problem at a site, specific contractual requirements, and individual state requirements is employed. Although no standard process in DoD to perform the site investigation currently exists, the product of the site investigation phase is an “Action Memo” that describes the problems and priorities within the site and delineates the suggested approach to restore the site. This document is used to initiate public involvement in the remediation process.

a. Site Survey

Site surveys require navigation/positioning and mapping for dry lands and wetlands. Navigation and positioning use Differential Global Positioning System (DGPS) in open areas, but require standard survey techniques when parts of the site are under canopy. Little wetlands work has been performed to date. Regulatory issues, physical access to all areas of the site, and the amount of manpower required generally dictate whether manual or advanced data-collection techniques are employed. Both computer and manual methods are being employed for mapping, with the necessary ruggedization of equipment generally precluding the use of advanced technologies in more spartan environments. Computer mapping is conducted using magnetometry and electromagnetic sensors that interface with remote workstations manned by specialized work teams. Manual mapping uses both handheld and towed sensors that can also be tied to digital data recording. Underwater mapping systems in use include side-scanning sonars, handheld sonars, diver communication systems, and DGPS with buoys.

b. Sampling

Different models and statistical approaches are used for sampling. The U.S. Army uses the technical project planning process while the U.S. Navy and the Environmental Protection Agency use the TRANSECT approach. There are no universally accepted statistical methods, and there is no standard statistical approach that ensures regulatory acceptance. In general, the statistical techniques are manpower intensive, and standards are generally established with the principal stakeholder at the project team level. Each site requires separate negotiation.

Dry land sampling utilizes DGPS in open areas and reverts to manual survey techniques under canopy. Computer mapping is performed with digital interfaces established to remote digital recording and transfer stations.

c. Inspection

Inspections are manpower intensive. Identification of various items is achieved through use of ordnance reference manuals. Various imaging technologies, thermal neutron sensors, X-ray backscatter, and acoustic sensing technologies have been tried as sampling techniques, but in general they are marginally mature. No baseline has been developed for a wetlands sampling process. Little wetland or underwater sample mapping has been performed to date.

d. Diagnostics

Current diagnostic techniques are manpower intensive, are time consuming, and are high cost items contractually. For dry lands, X-ray imaging, thermal neutron sensors, and imaging technologies can be employed as diagnostic instruments. For underwater applications, acoustic sensing techniques are generally used.

e. Data Collection, Cataloging, and Storage

The contractual statement of work drives the format for data collection, cataloging, and storage; there is no standard approach. Contractors bid and perform what is directed contractually, so the statement of work is the principal cost driver for all work performed in this area.

3. Detection

The diversity of unexploded ordnance makes detecting and locating it a difficult task. The sizes and shapes of unexploded ordnance range from small arms ammunition (lengths from centimeters to tens of centimeters), rockets (widths of 5–12 centimeters, lengths of 1.25 meters), mortar bombs (which generally are converted into flying shrapnel), artillery rounds (15 cm diameter), antipersonnel land mines (5 cm diameter, 1–2 cm height), antitank mines (30 cm diameter, 6–10 cm height), to bombs that weigh from 100 kilogram to 1 metric ton (lengths 1.5–4 meters). These devices are located on the surface and to depths of up to several meters. Each of these devices can be made of a range of metals and explosives, and in the case of mines, plastics are sometimes used as structural materials.

a. Visual Detection

A large amount of unexploded ordnance may be found on the earth's surface. Its presence on the surface may be an artifact of its initial deployment or a result of being brought to the surface by soil water, frost heaves, or other means. UXO on the surface can be visually or photographically detected and recorded. The presence of surface UXO is also an indication that subsurface UXO may be present.

b. Subsurface Detection

Three different types of detectors are currently used for subsurface detection of UXO: magnetometers/gradiometers, active electromagnetic induction techniques similar to that employed in mine detectors, and ground-penetrating radar (GPR). The most common type of detector used is the magnetometer/gradiometer. The term "mag and flag" stems from the use of magnetometers to detect buried ordnance and flags to mark the position to be interrogated. Magnetometers such as the Schonstedt fluxgate GA-52C or the Foerster Mark 26 are typically used in the field. In areas that include large amounts of metal clutter (e.g., shrapnel), the performance of magnetometers and gradiometers is substantially decreased. Active electromagnetic induction techniques are useful for finding small items near the earth's surface. Electromagnetic sensors such as the Geonics EM31 are useful for finding ordnance at sites that are composed of nonferrous metals such as copper and aluminum. Towed GPRs are used in some environmental situations. Generally, towed GPR systems work well in sandy or dry soils. GPR systems are significantly less effective working in clay soils or sites with a high-saline water table. In addition, significant amounts of ground vegetation also affect the performance of GPR systems. Although a wealth of high-technology detection techniques have been discussed in the countermine, geophysical, or academic literature, little new technology is available, affordable, or adaptable to many of the severe conditions imposed by field environments or contractual requirements. The standard approach to UXO detection remains "mag and flag" because of its capability, adaptability, and ease of use in a wide variety of sites and environments.

4. Access/Excavation

Access and excavation can be a time-consuming process. Depending on the situation, gaining access may require excavation and removal of brush and overgrowth. Getting equipment to the site can be very challenging, particularly when unique

environments require extensive health and safety planning. The problem consists of evaluating surface and buried ordnance in dry and wetlands.

a. Land Surface UXO

Equipment used to clear surface areas includes manual, mechanized, and remote-controlled items. Manual access is done visually and on foot using machetes, shovels, hand rakes, and hoes. Mechanized access is established using armored bulldozers or armored loaders and excavators. Currently there are no established methods for using remote-controlled vehicles. Personnel protection is required in the form of blast shields and bomb suits, although there are no clearly established procedures and designated equipment. Site protection is established through the use of earth berms and blast blankets.

b. Buried UXO

Manual hand excavation using shovels, hoes, and augers is widely used during UXO access and excavations. Front-end scrapers, tillers, and armored bulldozers are mechanized methods for attacking buried UXO. These manual and mechanized technologies are mature and readily available. Remotely controlled excavators, while available, are not widely used by industry.

c. Wetlands UXO

There are no standard approaches for providing access to wetlands areas. Underwater UXO requires divers, but no baseline exists for providing access to underwater UXO.

5. Neutralization

Neutralization includes disablement and destruction of UXO.

a. Disablement

Non-energetic disablement techniques used today include cutters, crushers, shredders, hydraulic shears, and some applications using hydrojet cutting. Energetic disablement techniques currently employed include blowing-in-place, bulk explosive charges, shaped charges, burn-through flares, and perforators. No explosive desensitization techniques are being used. Personnel and site protection consists of using sand bags, trenches, enclosures such as the Donovan blast chamber, and roll-off boxes coupled with specific engineering controls. A computer database is used to track UXO

disablement. There is limited baseline of techniques for underwater disablement. Generally, energetic techniques such as blow-in-place, bulk explosives, shaped charges, and flares are applicable to underwater applications. None of the non-energetic disablement approaches used in dry lands or wetlands are easily adaptable to underwater applications.

b. Destruction

Non-energetic methods currently being used for destruction of UXO include cutting, crushing, and shredding. Some hydrojet cutting is also being utilized. Blow-in-place, bulk explosive charges, open burning, shaped charges, and flares are used for energetic destruction of UXO. No method is used to chemically desensitize UXO. Personnel and site protection utilizes sand bags, trenches, roll-off boxes, water, and explosive enclosures. UXO tracking is performed using computer databases. As is the case for disablement, there are a limited number of cases for dealing with underwater UXO. Current UXO destruction is limited to energetic technologies.

6. Recovery

Recovery of UXO includes not only the UXO, but also the associated energetic materials and collateral materials. Each of these areas consists of materials handling, transportation, storage, and data collection.

a. UXO Recovery

In general, materials handling is performed manually. Technical inspections are conducted in the field, and materials are consolidated within a grid system. In some cases, energetic materials are removed on site. Fuzed munitions are not moved, and there is limited on-site movement of UXO. Items are placed in existing magazines, roll-on/roll-off boxes, or lock tubs. An audit trail is performed for all UXO and entered into computer databases.

b. Energetic Materials

Energetic materials are manually inspected and in some cases removed from the UXO. The materials handling is consolidated within a grid system. The on-site movement of these materials is limited. Roll-on/roll-off boxes and lock tubs are provided for storage. All energetic materials are tracked in a computer database.

c. Collateral Materials

Manual collection and segregation of non-energetic materials is performed on site. Non-energetic materials are removed more readily from site. All materials are tracked in a computer database.

7. Disposal

Three basic types of items require disposal: UXO, energetic materials (explosives, propellants, pyrotechnics), and collateral materials. Four matters must be addressed in each of these cases: the handling, processing, and disposal of materials (reactive and inert); transportation of items and materials; storage of same; and data collection. The items being treated are, of course, capable of causing damage and are handled accordingly. Transportation is limited to the extent reasonable and possible. Fuzed munitions are not moved and must therefore be disposed of in place by appropriate means. Other items are treated by what are basically the brute-force methods of physical disintegration and burning. While the items are still hazardous, they must be stored in secure containers that are readily handled. Custodial accountability for all items must be strictly kept. Data on disposed items are collected and tracked by means of a computer database.

a. Unexploded Ordnance

The baseline methods for disposal of UXO are outside (open atmosphere) burning and outside detonation (blowing in place) of ordnance items. Devices and methods available for disposing of small arms items in enclosures provide some control of the products of reaction. Devices are also available to crush, shred, or shear items and to dispose of associated energetic materials in furnaces, kilns, and smelters.

Transportation of items is either manual or by vehicle when possible, but as mentioned earlier, fuzed munitions are not moved. Baseline storage methods are roll-on/roll-off boxes. A chain of custody is established in association with storage. Data on the disposed items are likewise collected and are tracked in a computerized database. Concurrently, soil samples at the site are collected.

b. Energetic Materials

Disposal, transportation, storage, and data collection of energetic materials are handled in much the same way as unexploded ordnance, except that the items are not in munitions configurations. Nonetheless, extreme care is needed in their handling. Outside

burning and outside detonation remain the baseline techniques for disposal. Storage must account for the hazard inherent in the materials, and transport is kept to a reasonable minimum. Accountability for the material must be established and maintained.

c. Collateral Materials

Other materials are collected and disposed of according to Environmental Protection Agency regulations. This places unique requirements on each remediation task.

8. Monitoring and Stewardship

This is perhaps the most complex aspect of UXO activities. Monitoring and stewardship involve a range of issues from the deeply scientific and technical, to pragmatic matters, to personal values and judgments where there are no “right” answers in the scientific sense. This spectrum is reflected in the activities covered: risk assessment and prediction, risk awareness and communications, site monitoring, site security, and public outreach. The focus of these activities is, of course, the avoidance or minimization of risk to individuals and the environment owing to immediate physical trauma or long-term health hazards. This calls for sound technical capabilities and sound understanding of public needs, wishes, and expectations for remediation and security.

a. Risk Assessment and Prediction

This calls for assessment of the current and anticipated hazards from UXO and from energetic and collateral materials. Currently this is done in the field by various qualitative methods. Several methods with quantitative capabilities are available for application. Use of the quantitative or qualitative methods requires a benchmark in the form of agreed levels of acceptable risk for each specific instance of remediation. The predictive aspect is necessary for the long term with regard to planning and executing site monitoring, site security activities, and doing beneficial public outreach.

b. Risk Awareness and Communications

A benefit of risk assessment and prediction and of an effective site-monitoring program is a soundly based continuing awareness of the health of a remediation site. Such awareness will serve to maintain constructive interaction among stakeholders in the health of the remediation site. Current practice is to maintain continued dialog and interaction with stakeholders by using the most effective practical means, including videotapes, posters, Web sites, and other communication media.

c. Site Monitoring

The purpose of site monitoring is to remain vigilant to the status of the remediation area, and to do so in relation to the remediation exit criteria, and the risk assessment and prediction. Current practice is to do long-term and short-term sampling of cleanup sites using techniques appropriate to the hazards at the site (e.g., UXO detection or soil and groundwater contamination monitoring).

d. Site Security

When a cleanup site is assessed to have residual risk (or a potential for risk) after initial remediation is completed, an appropriate security system and plan must be implemented. The level and nature of security for the risk must be agreed on by the responsible parties and stakeholders. Current security practices incorporate a variety of approaches, such as fences, signs, and guards in various combinations. They are complemented by periodic review of site security.

e. Public Outreach

A technically perfect remediation program that the public and stakeholder do not credit is an unsuccessful program. The remediation community recognizes this, so considerable effort is spent to make sure that the public accepts the remediation programs. Current practices to achieve this include stakeholder participation in areas such as project planning, Web sites, newsletters, and press releases.

B. AVAILABLE TECHNOLOGIES NOT CURRENTLY EMPLOYED BY MUNITIONS RESPONSE INDUSTRY

1. Archival Search

The technologies that can be brought to bear on ASR activities all fall into the categories of information and data management. These areas are relatively mature and rich with computer-based utilities that can be used to great advantage. Here, the critical need is for disciplined consideration by all members of the UXO remediation community of what is desired of the information and data management process. This must be done before selecting or specifying particulars of protocols and the like.

General features that warrant strong consideration for any computer based data/information management system include an open architecture that readily allows new features to be implemented, compatibility with diverse data formats and protocols,

ease of data transfers between systems, and adaptability to field use. For both the process and any computer-based support to the process, it is critical that such a system be flexible and adaptable to the diversity of remediation situations. Otherwise, it will be a burden, not a benefit.

The information and data management needs of the activities that make up ASR are briefly noted below.

a. Data Quality Objectives

A computer-based standard library of data quality objectives that are agreed upon by stakeholders in the remediation process would speed up early stages of a remediation task and provide some standardization. The library should include flexibility on objectives in recognition of the varied nature of remediation situations.

b. Data Collection

Standard graphic, text, and data formats are needed for source and generated documents (e.g., computer-aided design and geographic information system files). This applies to newly generated information and to those situations where manual data collection is transferred to digital formats. Transportability and interchange of these data to other services and users should be a priority capability. Similarly, compatibility with other computer-based portions of the remediation process is a must.

c. Data Cataloging

Cataloging must be internally consistent and convenient across the entire remediation process, and it should have maximum consistency and interoperability with important databases critical to the remediation process (e.g., those of the United States Geologic Survey, and the National Imagery and Mapping Agency).

d. Data Storage

Storage needs to be standardized, flexible, and convenient. The standardized formats should allow central mass storage or netted distributed storage. There must be a means to characterize and ensure data quality. Data must be readily accessible through the Internet in formats adaptable to the needs of individual users for office or field use.

e. Data Retrieval

Data retrieval should be fast, convenient, and suited to user needs and specifications. Technologies are at hand to do this, but a system that addresses the needs of the UXO remediation community in the field and in the office has to be provided.

f. Data Presentation/Visualization

Standard, generic formats need to be established and made conveniently available. Adaptability to special needs and situations should be incorporated in the standards.

g. Data and Information Analysis

The outcome of an ASR should include an initial basis for the engineering evaluation, cost analysis, and other follow-on elements of a remediation task. Computer-based (or assisted) analysis tools are needed for optimum exploitation of the information gathered and processed in an ASR.

2. Site Investigation

DoD has wide latitude to provide a range of responses and set priorities for each site investigation. The question is, What forms of standardization in ASRs and site investigations would lead to meaningful improvements in the remediation process? Because DoD sites span many states and the remediation process itself has overlapping issues with other federal agencies, many opportunities for standardization are potentially precluded by divergent laws and regulations. Provision for searchable ASRs could lead to greater efficiencies during the site investigation phase.

a. Site Survey

Although manual methods are the norm for site surveys, wide-area surveys tied to accurate digital geophysical mapping would create opportunities for future efficiencies in conducting the survey, thus improving the remainder of the remediation process. These improvements, of course, require the use of high positioning accuracy and navigation. New laser and acoustic navigation tools that would enable these improvements are becoming available. Underwater improvements needed include the development of an underwater equivalent of the DGPS. Side-scanning and diver-held sonars need to be integrated into an underwater DGPS system. Computer mapping tied to this interface would provide new underwater capabilities to rapidly and accurately establish underwater surveys of wetland areas.

b. Sampling

Although impressive statistical sampling methods have been employed at some sites, there currently exists no universally acceptable statistical sampling process within DoD, industry, the individual states, or other federal agencies. Many regulatory issues loom over developing such a process, along with the problems associated with convincing the general public of a single, statistical model that would work in all environments and at all sites. Corollary issues include establishing standardized definitions for statistical sampling accuracy and sample location. Sampling techniques and approaches are also very sensitive to the underlying assumptions and statistical methods employed. The greatest immediate benefits appear to lie in establishing a coordinated team approach in which all the stakeholders work to establish a common, acceptable statistical model that is meaningful for an individual site.

c. Inspection

Current inspection techniques are manpower intensive. Improvements can be effected through rapid, nonintrusive inspection tools and techniques. Improved imaging sensors and signal processing can provide quicker inspections and concomitantly obviate the need for handling UXO. Fielded, digitized databases could also be used to speed the inspection and identification process. Two emerging, albeit high-cost, technologies for mine detection could provide faster, nonintrusive views of buried UXO: X-ray backscatter technology and thermal-neutron-activation techniques. Advanced sonar techniques could be applied to underwater inspection of suspected UXO targets.

d. Diagnostics

Current diagnostic techniques are slow and manpower intensive. Although the advanced technologies mentioned above are also appropriate for performing diagnostics, they are expensive and require specialists to employ them.

e. Data Collection, Cataloging, and Storage

Data collection, cataloging, and storage can also benefit from standardization. These areas not only share the problems previously mentioned (diverse regulatory, state, federal, stakeholder interests), but also are driven by contractual and cost constraints. Standard data-collection formats, software to rapidly handle large data arrays and databases, and data-collection software would provide numerous benefits in all phases of

the remediation process and could serve as a meaningful basis on which to base future site evaluations.

3. Detection

The principal technologies that are newly used in, or hold promise for, UXO detection include the following:

- Magnetometers and gradiometers.
- Electromagnetic induction.
- Ground-penetrating radar.
- Visible imaging.
- Infrared radiometry and imaging.
- Millimeter-wave radiometry.
- LIDAR (light detection and ranging).
- Nuclear technologies.
- Acoustic technologies.

a. Magnetometers and Gradiometers

Magnetometers and the associated technology of gradiometers are the mainstays of UXO detection, even though they are only effective against ferromagnetic materials. Several means have been pursued to enhance their sensitivity and effectiveness. Three-axis fluxgate magnetometers provide the direction from the sensor to the object; when used in conjunction with a gradiometer, they also provide the distance to the object.

Devices that exploit the “Overhauser effect” significantly enhance resolution in detection and at the same time reduce device power consumption. They also benefit from enhanced response times compared with earlier technologies. Additional technologies that have promise for exploitation in magnetometers are electron tunneling and fiber-optic devices.

b. Electromagnetic Induction

This concept strives to exploit the fact that many materials will retain some residual magnetization when exposed to a strong magnetic field, such as that generated with electromagnetic devices. This residual field could then be used to detect UXO.

c. Ground-Penetrating Radar

Over the last decade, significant strides have been made in the area of ground-penetrating and foliage-penetrating radar technology. Some of this technology is in use today, and further exploitation seems likely. As hardware and signal-processing algorithms are developed and improved, accuracy and discrimination will correspondingly improve. Benefits are also anticipated for detection of surface UXO in areas of vegetation where foliage-penetrating radar can be used.

d. Visible Imaging

In general, visual imaging for detection is in a position to exploit all advances in imaging, image enhancement, and image interpretation that are available. In particular, advances in image interpretation and information gathering appear to have significant benefits.

e. Infrared Radiometry and Imaging

Multispectral and hyperspectral devices are pursued owing to their potential in airborne applications and their capability to detect volatile constituents of unconfined explosives. Various contributing technologies are being investigated to enhance the capabilities of infrared devices for UXO detection. These include new optics and filters that provide “spectral agility.”

f. Millimeter-Wave Radiometry

This technology uses much the same techniques and principles as infrared radiometry. Compared with infrared, it suffers relatively little degradation owing to weather, but on the down side, target/object emittance is low compared with infrared.

g. LIDAR

This technology uses the reflected light from a laser source to detect and define the position of targets on the ground. The approach can be used effectively during the day and at night, but it is limited to detecting and classifying surface objects.

h. Nuclear Technologies

Explosives characteristically contain large amounts of nitrogen, hydrogen, and oxygen. Nuclear technologies exploit this distinction from the explosive’s surroundings by exposing the region in the vicinity of a buried explosive to radiation that will excite

one of the three elements in the explosive. The unique signature emitted by the explosive can then be detected. Two means for excitation are under study: electron-beam X-ray activation and thermal neutron analysis.

i. Acoustic

Scattering of acoustic and seismic waves propagated through the soil is being developed to detect objects buried slightly beneath the earth's surface.

4. Access, Location, and Excavation

Access and excavation are time consuming. The potential of newer tools is correlated to whether the sites are land surface or wetlands.

a. Land Surface UXO

Advances in preparing land surfaces for site access are limited to improved mechanized techniques such as the KROHN tiller, improved unmanned ground vehicles, and robotic systems.

b. Buried UXO

Advances in gaining access to buried UXO are limited to the use of improved mechanized techniques as in the preceding paragraph.

c. Wetlands

Because of the limited demands for remediation of wetland and underwater UXO, little technological help will be available in the short term.

5. Neutralization

Emerging technologies and programs that will provide new neutralization techniques can provide both UXO disablement and destruction. The Zeus laser-neutralization system can be used to initiate either deflagration or detonation of surface ordnance or of ordnance for which the soil overburden has been removed. The laser is expensive to purchase and requires specialized training. Alternatively, if contractors are used, rental and support costs will be high. Environmental Science and Technology Certification Program (ESTCP) demonstration and training programs for cued identification offer another alternative for improving the effectiveness and capability of

the neutralization process. No new underwater neutralization improvements were identified for potential implementation in the next 2 to 5 years.

6. Recovery

The recovery of UXO is primarily driven by laws and regulations that require proof that energetic materials and collateral materials have either been destroyed or appropriately segregated and removed for proper disposal. Regulators typically want consolidated disposal in Donovan Chambers or in-grid verification of explosive material removal. Items that could expedite the recovery process include field-usable kits to perform forensic analysis of material fragments or vapor sensors to measure concentrations of energetic materials. Mechanized systems that remove vegetation from the soil and screening methods to demonstrate the levels of energetic materials would be helpful. Finally, methods to dewater contaminated soil would aid in the recovery process.

7. Disposal

Significant benefits are to be gained in hazardous materials disposal from the development of new technologies and the exploitation of existing technologies. This is recognized by the remediation community, as is the strong need for developing, agreeing to, and using standard guidelines and procedures. Nonetheless, no currently available technologies have been identified for new field use. The Strategic Environmental Research and Development Program (SERDP) and the ESTCP may provide technologies to exploit. For each category of material that must be disposed, there is a need for standardized procedures and guidelines for data management. Technologies are available to manage data once standards are set.

a. UXO

Recognized technology needs for UXO disposal include the means to break down energetic materials; hot gas decontamination; and removal, degradation, or recovery of energetic material residues from scraps. Particularly important are technologies to satisfy these needs on site in a safe and economical fashion, thereby alleviating the need for special transportation and storage. The principal needs for transportation and storage are in the category of setting standard procedures and guidelines. Nonetheless, technologies that will allow faster and surer inspection and confirmation of the condition of stored items are also needed.

b. Energetic Materials

The needs for energetic material disposal, transportation, and storage parallel those for UXO in large measure, with the understanding that these materials are not normally fuzed. Regardless, certain energetic materials—pyrotechnics for example—are much more sensitive than the materials typically found in munitions and therefore call for extreme care in handling and treatment. Also, energetic materials disposal has special needs for in-situ soil monitoring at remediation sites.

c. Collateral Materials

The requirements for disposition of collateral materials are unique for each remediation task and are regulated by the Environmental Protection Agency.

8. Monitoring and Stewardship

The areas where technology has the greatest potential for benefit are risk assessment and prediction and public outreach. The monitoring and stewardship areas are assessed to benefit the most from common, standardized guidelines and protocols and effective methods of communication among stakeholders and with the public at large.

a. Risk Assessment and Prediction

Members of the remediation community (e.g., U.S. Marine Corps, U.S. Army, U.S. Navy) have developed models for risk assessment and prediction. Effort is needed to exploit them effectively in the field. Further work is needed to improve capabilities to determine hazards and toxic risks. Fate- and transport-prediction models and risk-simulation models are needed.

b. Risk Awareness and Site Monitoring

No currently available technologies ripe for field use have been identified. Recognized needs are in the areas of standardization, monitoring protocols, and effective communication strategies.

c. Site Security

No currently available technologies ripe for field use have been identified. The need to reduce site encroachment is recognized. Methods and technologies developed under Homeland Security initiatives should be monitored for applicability to this need.

d. Public Outreach

Several training courses have been developed to train and educate stakeholders, managers, and commanders on site remediation. There is a need to get this and other relevant training to the individuals and groups requiring them. Recent developments and accomplishments in advanced distributed learning are well suited to these needs. Advanced distributed learning exploits sharable courseware and Internet connectivity to provide training where it is needed (at home or in the office or work site), when it is needed, with the content targeted to specific needs.

V. TECHNOLOGY RESEARCH AND DEVELOPMENT

A. TECHNOLOGY RESEARCH

1. Cued Identification

An effort (http://www.estcp.org/projects/uxo/200036o.cfm) is ongoing to build upon electromagnetic induction (EMI) technology by measuring the broadband electromagnetic spectrum over targets and use software to compare the observed spectrum with a stored library of spectra from known UXO targets and thereby provide a basis for discrimination. This approach requires development of a broadband EMI sensor that operates up to ~50 kHz—in contrast with most detectors that operate at a single frequency.

Another effort (http://www.estcp.org/projects/uxo/200108o.cfm) underway seeks to exploit EMI phenomena by preprogrammed control of the sensor head in a sweep pattern over an unknown target. A model-based estimation procedure uses the spatial pattern of the induced field to determine whether the target is likely to be a UXO item.

A patented method called Sub-Audio Magnetics (http://www.estcp.org/ projects/uxo/200322o.cfm) also has active support for detection and discrimination of UXO. It utilizes a closed-loop wire that may encompass up to several acres that are to be searched for UXO. This wire is energized with a low-frequency current (~32 Hz.). The enclosed area is then systematically scanned and total magnetic field data are gathered. Post processing separates the total magnetic field intensity and the total field electromagnetic transient response, which is used for detection and discrimination of UXO. Location is provided through GPS location data gathered with the electromagnetic data.

The benefits of exploiting the characteristics and processing of data gathered by magnetometers and EMI devices are generally recognized. This has motivated support for ways to develop and exploit physics-based models and other methods to gain an optimal match between modeled and measured sensor response to thereby have a basis for discriminating UXO from clutter. One such a study is underway at AETC Incorporated and Duke University with ESTCP support.

Even with a good discrimination capability provided by enhanced magnetic and EMI technologies-based devices, the basis for these devices is still detection of some metal thing that has characteristics (e.g., shape) representative of ordnance. There is clear benefit for remediation in positive identification that a buried (to be dug up) target contains materials characteristic of explosives. A technology with prospects (http://www.estcp.org/projects/uxo/200106o.cfm) to do so exploits pulsed neutrons. The neutrons excite identifiable energy states in materials such as hydrogen, nitrogen, carbon, and oxygen. Data on their behavior may be captured and analyzed to establish whether explosives are likely components of the presumed UXO target.

2. Decision Tools

UXO remediation tasks for large areas present special problems in terms of the sheer size of the job, the nature of the terrain involved, the potential diversity of the nature and disposition (e.g., buried, on the surface) of the ordnance, and the alternative methods and devices available for detection. To render such tasks manageable, a means should be at hand to guide the design and execution of hazard-identification programs in an optimal way (in terms of benefit gained for effort expended). Furthermore, the means should include understanding of the reliability of the remediation achieved—that is, the display of residual risk levels for undetected targets in the remediation area.

Statistical methods provide capabilities of the type required for UXO remediation of large geographical areas. They are being pursued under SERDP sponsorship in a program called Demonstration and Performance Assessment of Statistical Methods for UXO Characterization. The methods under study include one for guidance of optimal survey schemes for detecting areas of specified geometry and another for determining the number of geophysical transects needed for confidence estimation of the likelihood of little or no UXO remaining at a site after remediation.

The desired outcomes of these efforts are software tools that facilitate tradeoffs between cost/burden of detailed characterization and risk levels of not finding UXO. The tools should also provide decision support for optimal sampling designs for UXO detection, for anomaly and UXO density estimation, and for verification after remediation.

3. Production Ground Surveys

Production Ground Surveys have the difficult task of detecting UXO over large tracts of land having any topography and vegetation. The multi-sensor towed array

detection system has demonstrated significant capability for these tasks through use of magnetometer and EMI technology sensors in combination with GPS location devices. Unfortunately, difficult terrain frequently obstructs or blocks the vehicular towed system. Further, significant benefits for the system would accrue from enhanced discrimination/clutter-rejection capability. Active programs are currently underway to address these two limitations. A portable adjunct to multi-towed array detection system that exploits its low-noise sensors, precise sensor location capability, and data analysis system is being developed. To do so effectively, special features must be incorporated for sensor physical stabilization. For situations where GPS navigation is not available, alternative position location devices, such as laser or acoustic navigation, will be used. Enhanced discrimination capability is the objective of a program that exploits an array of frequency-domain geophysical electromagnetic sensors and data analysis algorithms in conjunction with upgrades to current multi-towed array detection system equipment. Broadband data will be gathered by operating the sensors at a select set of frequencies. Data processing is expected to provide enhanced discrimination.

Implementation of EMI technology in a basic sensor typically involves a single receiving antenna used with some data-gathering and analysis techniques. Such devices used with GPS devices can be capable of detecting and locating most metal targets of concern with high confidence. However, the majority—perhaps an overwhelming proportion from a practical standpoint—of these targets is usually found to be non-UXO clutter. A program designed to overcome this problem exploits the information provided by three cart-mounted orthogonal receiving antennas used in conjunction with a single transmitter coil. The receiver sampling rate will be greater than four samples per second and thus will provide data on the early time transient behavior of target conductors. Data from the enhanced set of three receiver antennas, when used with companion data analysis software, is expected to provide significantly enhanced target characterization ability and thereby reduce false alarms.

The use of magnetometer and EMI detection data in combination provides enhanced detection probability and better target characterization information. However, simultaneous magnetometer and EMI data gathering from a single platform presents some electronic noise problems for magnetometer detectors, with associated degradation in data quality. A program is underway to address this circumstance by interleaving the magnetometer and electromagnetic pulse data acquisition. Electronics will be developed that sample magnetometer data only after the pulse for electromagnetic detection has diminished to the point that magnetometer noise is avoided. The program will exploit

appropriately modified surface towed ordnance locator system equipment to realize the concept. Data obtained with the common platform will be linked in time and location, thereby providing rich opportunities for data analysis to characterize targets.

4. Recovery and Destruction

Once items of hazardous ordnance are detected and characterized, the task of destroying or otherwise rendering them safe must be done in a way that presents no hazard to personnel, equipment, etc. in the vicinity of the item. In particular, there is emphasis on avoidance of injury or insult to the environment and wildlife. Effective alternatives are needed to the traditional methods of “blow in place” and removal to a “burn pit.” Several alternatives are under active study.

In those instances where the item of UXO must be destroyed in place or at a remote removal site, the benefits of standoff initiation and low-order reaction of the item are obvious. A project to achieve this is underway that uses a high mobility multi-purpose wheeled vehicle mounted with a self-contained 500-watt Nd: YAG laser system that focuses intense energy on exposed UXO from distances as great as several hundred meters. This provides safe distances for personnel, overcomes the use of additional explosive charges for destruction, and may initiate low-order reaction in the ordnance item. Demonstrations of the concept are to be done at Nellis Air Force Base during normal range-clearance operations.

Another laser-based approach to the neutralization problem exploits fiber-optic propagation of the laser energy for heating surface or buried munitions. This concept also is vehicle mounted for enhanced mobility and flexibility.

Hazardous energetic materials are not always explosives, nor are they only found in well-defined recognizable ordnance items. Besides explosives, there are hazardous propellants and pyrotechnics that must be recognized and rendered safe. These may come from range debris or from the scrap or waste of production facilities. Effective and environmentally safe methods to handle such contaminated items are important to have. The U.S. Army Environmental Center has developed a thermal-desorption technology that handles these problems. A program is underway to build a treatment facility that exploits this process. It is intended to demonstrate the affordability of doing so.

Clearance of UXO from practice ranges is a “regular as clockwork” requirement. One advantage gained from this practice is that the ordnance practice items are usually well described, and this information may be used to advantage in the neutralization

process. In particular, the energetic materials for “flash, bang, and smoke” in practice bombs may be neutralized by a hydrolysis process under development by UXB International, Inc. Advantages for the system are a minimal waste steam from the process and that the inert components can be recycled.

Final mention is provided for efforts addressing the problem of detection and removal of ordnance during dredging operations. Special care must be given to problems associated with the actual dredging, but also to the task of ensuring that UXO in dredged sediments have been detected and properly handled. A three-phased effort is on going to address this problem. The first phase will do a survey of historical data on dredged sediments containing ordnance and identify potential demonstration/validation sites. It will also include field observations of dredging operations with a view to evaluation of safety measures and to develop specification for Phase II dredging and separation effort. Phase III will analyze and report results.

5. Standards and Protocols

The quality and value of the results of tasks undertaken for detection, discrimination, and ultimate remediation of UXO sites depend significantly on the reliability and accuracy of the data gathered in field operations. It is vital that the data gathered on field surveys are of adequate quality to ensure that target “hits” are uniquely identified and that their locations can be revisited with confidence. It is necessary for practical reasons to return to specific places for verification and remediation. Further, it is necessary for confident demonstration that the remediation claims have been achieved. The importance of quality position tracking is evidenced by the level of support it has in UXO technology programs. GPS systems are foundation elements of position location, but frequently are not usable or sufficiently reliable owing to terrain and foliage masking and to terrain multipath effects. Hence, adjunct digital geophysical mapping systems are required in a significant percentage of instances. One such ground-based system under study exploits time-modulated ultra-wideband communications to precisely determine the distance between radio stations. The concept employs a set of accurately placed reference (base) stations and a device on the detection device. Accurate and reliable locations of potential UXO detections are thereby established. Owing to the low power levels involved, the system promises robustness in the presence of foliage and vegetation. It also provides a high-speed data link for transfer of sensor data. It is looked upon as an enabler for faster, better, and more economical remediation of UXO.

Another program directed to resolution of problems for achieving high-quality Digital geophysical mapping systems is conceptually similar to the one that looks to exploit time-modulated ultra wideband. It looks to time-of-flight ultrasound phenomena to provide the basis for tracking in UXO surveys and is intend for application in wooded areas in particular. The study will examine various characteristics of the concept including maximum range, stability and accuracy as range varies, and effects of obstructions on the ultrasonic signal.

The importance of position tracking for UXO remediation is further evidenced by the release of a request for proposals to select vendors for development of innovative navigation equipment and for accurate sensor tracking during digital geophysical mapping surveys. Up to five Phase I studies will be awarded for concept study, presentation, and demonstration. Phase I will focus exclusively on navigation equipment demonstrations. Follow-on phases will support the most promising approaches to integrate the navigation equipment with typical geophysical equipment.

The study efforts mentioned above are motivated by the need for quality position tracking data. Of course, the need for quality exists throughout the UXO business, and it begs for standards and means through which the performance characteristics of equipment and procedures may be benchmarked. A recent initiative to establish standardized UXO technology demonstration sites recognizes these needs and is intended to satisfy them. Two initial sites will be established at Aberdeen Proving Ground and at Massachusetts Military Reservation. They are to provide the technology developer with standardized sites for UXO sensor technology testing and demonstration. Each site will consist of three areas: a calibration lane, a blind grid, and an open field. These will provide diverse opportunities for technology developers to characterize, demonstrate, and document the performance of their systems and devices.

With motivation similar to that for the demonstration sites, there is also a program to establish quality control and quality assurance software for digital geophysical mapping. It is being pursue throughout the U.S. Army Corps of Engineers Engineering and Support Center at Huntsville, Alabama, with the goal of establishing a quality control and quality assurance tool set to improve field data by identifying and correcting instrument and acquisition errors before standing down data-gathering activities. This will allow better and less expensive products by reduced rework. It is also expected to enable shared analysis algorithms by providing a standard platform for developers.

6. Wide Area Assessment

The nature of the UXO remediation task leads naturally to the desire for airborne methods for detection, characterization, and identification of targets. Airborne surveys may overcome significant portions of the challenges to ground surveys posed by large—vast in some cases—areas to be surveyed, by terrain that is difficult to impossible to survey on the ground, and by cultural or hazard restrictions. However, as with many things, this proves harder to accomplish than one originally expected. For instance, problems of survey accuracy from moving air platforms are anything but incidental, as are those of sensor performance at remote distances from the target UXO (compared with the proximity in ground surveys). Significant capabilities have been gained to resolve these problems and vigorous research is still underway.

The multi-sensor towed array detection system has done an effective job of integrating satellite-based position-location systems, advanced sensor systems—magnetometers in particular—and data-analysis utilities for ground-survey tasks. Exploitation of these technologies for airborne applications requires methods to correct the airborne magnetometer data for air-platform-induced effects. Other work in airborne submarine detection and mining exploration for correction of air-platform effects is also at hand. A program is underway to exploit these accomplishments with the goal of detecting and classifying targets in the sizes of general-purpose bombs and gun-fired projectiles. The objective is to be able to survey over 650 acres per day. A capability to survey shallow-water locations is an expected capability of the system.

Some success has already been achieved with airborne magnetic detector systems. Methods to augment these systems certainly would enhance data reliability and confidence; they could also serve as an alternate detector when magnetic sensing proves difficult or unreliable. Activity is on going to develop airborne EMI devices for this purpose. Two systems are to be tested, and the more successful of the two will be developed, designed, and constructed, assisted by electromagnetic system modeling.

Final mention is given to work on the use of recent investments and advances in the understanding of airborne synthetic aperture radar. With the capability to detect items in deep foliage, it is frequently referred to as foliage penetrating radar. Work is ongoing to examine the utility of this capability in UXO-contaminated areas.

B. INDUSTRY FORUM

The Joint UXO Coordination Office hosted a UXO-Environmental Remediation Technology Workshop on 15 July 2003 at the BRTRC Corporate Headquarters in Fairfax, Va. The objectives of the meeting were to discuss existing barriers and solutions to technology applications, as well as regulatory, contractual, and liability issues. The agenda included presentations by U.S. Army Engineer Research and Development Center, U.S. Army Corps of Engineers, Navy Munitions Response Program, the Kaho'olawe project, and the National Association of Ordnance and Explosive Waste Contractors (NAOC), as well as industry talks from AETC Incorporated and Blackhawk GeoServices, Inc.

While government and industry agree that some form of demonstration and validation program is essential to the development of new and useful products, the critical issue is developing a process or capability to meaningfully transition new products to industry. The following are some of the key issues surrounding transition:

- Who decides what new products are needed, and how is this done?
- When and how is it decided that the products are ready for transition?
- How is the transition effected, and who is responsible?
- What are technology transfer tools?

Industry pointed out that while the research and development community provides solid technical contributions, it has a limited understanding of the needs of the UXO remediation community. Furthermore, the research and development community does not understand the constraints (e.g., physical, environmental, contractual, legal) in which the UXO remediation community operates.

Industry also noted that "technology transfer" is defined and implemented differently by various governmental organizations. The consensus was that to date, "the technology transfer phase process would take care of itself without formal intervention." Now, it appears that it may be necessary to identify an end-state development before technology transfer is initiated.

Industry and government agreed that nontechnical factors also have significant impacts on the transition of new products for use in UXO remediation.

- Contracting Barriers. These barriers include issuance of many smaller projects to numerous prospective contractors. This practice precludes an incentive to invest in new technologies that could apply to several sites. The cost of equipment can only be amortized over multiple projects.

- Capitalization Costs. The funding stream is unpredictable and historically is not growing. The capitalization costs associated with new technologies are generally not recoverable.
- Regulatory Issues.
- Liability Issues.

Ultimately, market size will determine industry capitalization in new technology areas. New technologies will be utilized and adopted only as they are financially rewarding. Therefore, technological leaps in UXO remediation technologies may have little or no impact if the current market size remains at its current level.

The UXO-Environmental Remediation Technology Workshop also considered potential solutions to the problems inherent in transitioning new technologies. DoD has an acquisition process for military technology transition; this process also supports peripheral issues such as training, logistics support, and modernization. There is no acquisition process to transition ESTCP and SERDP technology investments. This absence deters market growth for the UXO industry. The lack of a spiral-development process after transition requires each purchaser to make changes to hardware, software, and vendors independently, so that within a few years of purchase, the equipment is either out of date, modified to meet some particular requirements, or a one-of-a-kind piece. The training and support for the equipment necessarily follow each individual piece or application. Some possible solutions discussed at the workshop included the following:

- Government-furnished equipment and training.
- Performance-based contracting.
- Shared work using contract bundling.
- Program-based acquisition process.
- Multiyear funding.

Recommendations from the DoD UXO-Environmental Remediation Technology Workshop to improve the technology transition process included forming a strong partnership between government agencies and NAOC to aid in the growth of the UXO industry and establishing a direct input mechanism from the UXO cleanup industry and regulators into the technology development process.

C. TECHNOLOGY AND PROGRAM GAPS

Table 1 gives the requirements for countermine, explosive ordnance disposal, humanitarian demining, UXO environmental remediation, and active range clearance. The requirements determine not only acceptable technology approaches for each mission area, but also the type of training, scope of research and development, method of acquisition, and logistics support strategies required. Countermine and explosive ordnance technology receive the largest investments from the Department of Defense, not only in research technology investment but also in training, acquisition, and logistics support. Therefore, it is important to identify both technology and programmatic gaps in order to suggest alternative future plans.

Table 1. Comparison of Requirements for Different Mission Areas

	Mission Requirements and System Characteristics					
Mission	Effectiveness	Speed	Ease of Use	Size/Weight	Maturity	Casualties
Countermine	<100%	Critical	Complex	Critical	High (Rugged)	Mines/UXO, Direct Fire, Indirect Fire
Explosive Ordnance Disposal	~100%	Critical	Complex	Critical (Mission Dependent)	High (Rugged)	UXO
Humanitarian Demining	~100%	Not Critical	Simple	Not Critical	COTS	UXO
UXO Environmental Remediation	~100%	Not Critical	Complex	Not Critical	COTS	UXO
Active Range Clearance	~100%	Not Critical	Complex	Not Critical	COTS	UXO

Technically, only countermine or mine countermeasures accept less than 100-percent effectiveness in dealing with mines and UXO. The fundamental issue is that of maintaining a focus on the enemy and not on the mines. Mine detection, mine neutralization, and mine/minefield marking operations must be conducted in the presence of enemy direct fire and indirect fire. The longer countermine operations take, the higher the number of casualties from enemy direct and indirect fire. Therefore, speed is also a critical requirement. Consequently, countermine research and development efforts focus on technology solutions that can be rapidly deployed and employed against mines and UXO that are on the surface or within 12 inches of the surface. UXO remediation and

active range clearance require that a very high percentage of the UXO be eliminated to depths of several feet. The countermine technology investment requirements clearly do not include investments in technologies (detection, neutralization, clearance, location, and marking) that might be useful for each of the other mission areas. A similar argument can be made that military investments in explosive ordnance disposal technology also will not meet all the requirements for UXO environmental remediation or active range clearance. These gaps are generally the focus of the technology investments made by the ESTCP and SERDP programs (i.e., wide-area assessment, production ground surveys, cued identification, standards and protocols, recovery and destruction, and decision tools) and are discussed at the beginning of this chapter. Technology gaps can also be viewed as areas where current equipment or research and development technology efforts are ineffective or inefficient because of unique environmental problems or issues. Wetlands and underwater applications generally require special technology investments for wide area assessments, production ground surveys, cued identification, standards, protocols, recovery, destruction, and decision tools. With few exceptions, such as the Navy Munitions Response Program underwater detection program, technology solutions generally are not available for use in wetlands and underwater applications.

There are striking programmatic differences between the support levels within DoD for countermine, explosive ordnance disposal, and humanitarian demining and those available for UXO remediation and active range clearance. Countermine, explosive ordnance disposal, and humanitarian demining have specific users that develop and define user requirements and needs. Technology investments in these military areas are driven by user priorities. As is evidenced by the industry sentiment expressed at the UXO-Environmental Remediation Technology Workshop, the UXO remediation industry would like to become a major player in developing and prioritizing user needs.

A second programmatic difference concerns the transition from development to fielding. Countermine and explosive ordnance technology use DoD spiral-development acquisition guidelines for deciding products are ready for transition to the field. The transitions are effected through project managers and laboratories that provide full support for logistics, product improvements, and training. There is no corresponding structural or organization support of UXO remediation items upon transition from SERDP and ESTCP funding. Once a UXO remediation item transitions from the government, industry is expected to provide all logistics support, product improvements, and training. Again from the UXO-Environmental Remediation Technology Workshop, it is apparent that industry and NAOC recognize the problems and are trying to find

creative ways to improve their products and performance through the use of advanced technology. The shortcomings are known in both government and industry, but the lack of DoD involvement in the transition process is a major barrier to successful transition of technology to the UXO remediation industry.

D. BARRIERS TO TECHNOLOGY APPLICATION

Return on investment is a fundamental business principle. While there may be different ways to calculate the returns on technology investment, such as increased profits, increased market share, and improved deliverable products, it must be clear that the returns exceed the financial investment made by industry. The small size and slow growth of the UXO remediation industry are major barriers to technology investments.

In a relatively small and low-growth industry such as UXO remediation, there are few if any incentives for industry to make major technology investments unless there are corresponding changes in regulations or liability issues. Historically, changes in regulation and liability proceed at a glacial pace. It is unrealistic to assume that technology changes will drive changes in regulation and liability on a time scale that will provide meaningful returns to the company making the investment. Industry has indicated that changes in contracting could provide the necessary incentive for future investments in technology. These changes would include government furnished equipment, government furnished training, performance-based contracting, multiyear funding, and shared work using contract bundling. Contracting methods, regulations, and liability issues are also barriers to meaningful industry investments in technology.

The capabilities of the DoD acquisition process need to be considered, particularly with respect to transition from research and development to fielding. The DoD process requires user identification and prioritization of needed items, user evaluation of research and development items, approval of transition to fielded items, concurrent development of training and logistics support, and continued product improvement into the future. This is an expensive but necessary part of any fielding process. The barriers that exist today relate to current DoD and government organization, policy, and law and precedent. Most commercial industries do not have, or rely on, government investments for support in transition, but UXO remediation is a niche industry totally captive to government contracting and regulations. The industry relies heavily on employing previous military and DoD employees with experience in countermine, mine countermeasures, and explosive ordnance disposal and on using existent DoD tools and technology. Future investments in training, logistics support, and

product improvement are obviously needed, but the approach and investments may be driven more by future UXO remediation project requirements and legislation. Government and industry need to forge an approach that utilizes some forms of government support while remaining agile and responsive to the varying UXO remediation needs.

E. CONCLUSIONS

DoD sponsors a wide spectrum of technology investments to support countermine, explosive ordnance disposal, humanitarian demining, range clearance, and UXO remediation. DoD technology investments in UXO remediation are carefully reviewed to ensure that the investments either build upon advancements achieved in other related DoD mission areas or represent technology investments unique to environmental remediation. A diverse palette of capabilities is evolving to support wide-area assessment, production ground surveys, cued identification, standards and protocols, recovery and destruction, and decision tools. It is expected that this disciplined approach will achieve a progression of technology products that will build a solid technology base for UXO environmental remediation.

Industry surveys indicate that much of the technology investment has not transitioned to use in industry. Further, industry indicates that it is likely that much of the present DoD UXO environmental remediation technology investment may never find its way into common usage. Industry leaders point to several reasons the present UXO environmental remediation technology investment may not have the desired impacts on the future of their industry:

- Lack of user involvement in selecting and evaluating technology investments leads to products that may not meet the requirements of industrial use or may be useful in limited applications.
- At what point in development is a product deemed ready for transition?
- What process is used to determine that transition has been effected?
- Who (government, industry, or both) decides that an item has transitioned?
- Once transitioned, how are new technology products supported in the future?
- Can UXO remediation contracts be structured or bundled to encourage use of new technology products?
- How can industry recover their capitalization costs?

Government and industry need to work together to shape a meaningful transfer of useful technology tools to the UXO environmental remediation industry. Countermine and explosive ordnance disposal have built-in government programs to support the acquisition and fielding of new equipment through their project managers and laboratories:

- User definition process.
- Independent test and evaluation.
- User evaluation.
- Spiral development.
- Logistics support in the field.
- Training.

Industry has proposed solutions that include government furnished equipment and training, performance-based contracting, shared work using contract bundling, multiyear funded programs, and a program-based acquisition process. It is important that government and industry find common ground to develop a meaningful technology transition process. Technology investments without user selection and evaluation result in hollow products. Lacking a meaningful transition path, even good products fail for lack of proper training, product improvement, and logistics support.

GLOSSARY

ASR	archive search report
DGPS	Differential Global Positioning System
DoD	Department of Defense
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPR	ground penetrating radar
Hz	hertz
LIDAR	light detection and ranging
NAOC	National Association of Ordnance and Explosive Waste Contractors
SERDP	Strategic Environmental Research and Development Program
UXO	unexploded ordnance

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14. ABSTRACT

This report provides an overview and technology assessment of environmental remediation of UXO. The material presented in this report is intended to present an accurate picture of the present (baseline) and evolving (research and development) technologies used to address the remediation of UXO. The report addresses the investments being made by both government and industry in UXO remediation technologies and identifies technology gaps and barriers to technology application by industry.

15. SUBJECT TERMS

UXO remediation, training ground remediation, military base remediation, UXO clearance, BRAC Cleanup, UXO and BRAC used in same/nearby sentence, environmental remediation

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